

Los Alamos National Laboratory
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Characterization of Lithologic Variations
Within The Rock Outcrops Of A Volcanic Field

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CHARACTERIZATION OF LITHOLOGIC VARIATIONS WITHIN THE ROCK OUTCROPS OF A VOLCANIC FIELD

1.0 PURPOSE

This procedure establishes the methodology for characterizing the lithologic variations within rock outcrops of a volcanic field. Field methods used to describe individual outcrops and to establish stratigraphic relationships between outcrops of volcanic rocks are very similar to those used for sedimentary rocks and are described in textbooks on field geology (e.g., Compton, 1962). Careful geological mapping of lithologic units and establishing a stratigraphic framework is a crucial foundation for all other studies within a sequence of volcanic rocks. Without this framework, sample analysis is nothing more than rock collecting. Flexibility in the approach to a comprehensive field study must be allowed in order to determine what observations are appropriate to the rock sequence being studied. For example, the approach to field descriptions and sampling would differ considerably between that used for a large basaltic lava plateau and that used to study a group of small tuff rings.

2.0 SCOPE

2.1 Applicability

This procedure applies to geologists describing outcrops of volcanic rock within and adjacent to the Los Alamos National Laboratory for the purpose of characterizing the geologic setting during the Environmental Restoration program.

2.2 Training

Because of the remarkable complexity of the spectrum of volcanic rocks making up the plateaus occupied by the Laboratory, especially the pyroclastic rocks, descriptions of outcrops require at least an M.A. or M.Sc. in Geology and five years experience with these rock types. Researchers must document that they have read and understood this procedure and the procedures in Section 1.0, General Instructions.

3.0 DEFINITIONS

N/A

4.0 BACKGROUND AND CAUTIONS

When in the field, use common sense when moving from outcrop to outcrop and caution when measuring cliff sections. The best outcrops are always in cliffs, but access can be safely gained along scree slopes, road cuts, and stream bottoms. Follow procedures established in Group EES-1 for field work, which includes the location of your field traverses, time of departure, and estimated time of return. When working on outcrops along a highway, enlist an assistant to watch the traffic.

5.0 EQUIPMENT

The field equipment used by geologists is quite often a matter of personal preference. The basic equipment includes, field notebooks with perforated pages, Daily Activity Logs, ink pens for notes and pencils for sketches, optional camera (Polaroid, 35-mm, large-format, or all of them), rock hammer and chisels, small shovel for unconsolidated samples, sample bags, Geological Society of America rock color chart, Brunton Compass, altimeter, and meter tape (for stratigraphic sections), aluminum or stainless steel markers and nails for marking sample locations, and safety glasses for use during sample collection. Chain-of-Custody/Request for Analysis forms, Sample Collection Logs, Variance Logs, Custody Seals, Unique Sample Stickers, and Sample Labels will also be used. If oriented samples are required, then use of a gas-powered rock drill will be necessary.

6.0 PROCEDURE

6.1 Background

Rock units within volcanic fields show much more lateral and vertical variation than units in most sedimentary basins. They can fill caldera depressions or deep valleys making it possible for younger volcanic rocks to be present at a lower levels than older rocks before any folding or faulting. Pyroclastic rocks are formed quickly, initially with abundant kinetic and thermal energy and can be deposited as ashfalls draping topography, surges that cross topographic highs, pyroclastic flows that follow the valleys, and even wet surges of cohesive ash that defy the laws of original horizontally when plastered onto vertical surfaces.

Facies variations within single depositional units must be considered when mapping volcanic rocks. For example, surges and pyroclastic flows can grade outward into volcanic mudflows because of cooling and condensation of steam within the flow, some distance from the source. Pyroclastic flow units can vary in the degree of welding of pyroclasts, depending upon the unit thickness, with dense rocks near vent or in the center of valley fills. For detailed descriptions of facies variations in volcanic rocks, see Fisher and Schmincke (1984) and Cas and Wright (1987).

TABLE 1. STRATIGRAPHY IN VOLCANIC FIELDS (Adapted from Fisher and Schmincke. 1984).

PURPOSE	FIELD OBSERVATIONS
Correlation of lavas, tuffs, and epiclastic sedimentary rocks; eruption types; unit volumes; locating buried or eroded volcanic vents.	Individual beds; bedding sets in layered sequences; grain size; component analysis of features; fabric.
Paleotopography, and paleogeology; eruption history; depositional history; "basin analysis."	Facies analysis; creating a stratigraphy; descriptions of relations at unconformities;
Magma composition and volcano evolution; tectonic setting and volcanism; regional stratigraphy.	Relations of rock sequences to tectonic framework in time and space; comparison of volcanic fields, centers, and provinces.

6.2 Approach

Establish a working stratigraphy, based upon earlier published work and study of aerial photographs or topographic maps. Published stratigraphic studies supply useful information from nearby areas and may include radiometric dates. Compile all of this information in a notebook and on a map or photo base.

Quickly examine the whole area to locate the best exposures, especially those that show contacts between depositional units. Note these locations on maps and/or photographs and return to them later to measure stratigraphic sections. As stratigraphic data are collected, enter the information on ongoing cross-sections through the volcanic field. During the field season, some of your ideas on the stratigraphy will change and it will be necessary to revisit some outcrops several times to reevaluate your interpretations.

Measure sections at the best exposures, preferably in unfaulted areas. However, this may not always be possible. Begin by standing back and looking at the outcrop from a distance. How many layers or discrete rock units stand out? Mark them on a sketch or Polaroid photograph with their general characteristics, including thickness, texture or structure, and color. This "distance view" may be useful when unraveling variations from one detailed stratigraphic section to another.

When measuring a stratigraphic section, describe the attitude (strike and dip) of the rock units, descriptions of the rock types, and their relation to older rocks, paleosoils and any intrusive rocks. Mark the area traversed while measuring the section on a map or aerial photograph; if neither map or photo exist, prepare a pace-and compass map of the line with distances, slope angles and attitudes (strikes and

dips). Also note elevations, using an altimeter, of the base, top, and important contacts. If you are working with a team, use a tape measure;

If you are by yourself, a Jacob's staff can be used. If the stratigraphic sections are very thick, confirmation of thickness can be made by measuring elevations of contacts on a topographic map.

What will you be measuring and describing? Within the field, rock-stratigraphic units are defined solely on physical differences. Fisher and Schmincke (1984) define a formation as a "mappable bed, bedding set or sequence of beds of any thickness set apart from rock units above and below by distinctive physical criteria such as texture, color, lithologic or mineralogic characteristic, or by weathered zones or erosional unconformities; a member is a convenient subdivision of a formation." They also define the concept of an eruption unit, which is a deposit from a single eruptive pulse, eruptive phase, or an eruption. A sequence of several eruption units can be treated as a mappable unit or formation. Eruption units can refer to pyroclastic fallout deposits, pyroclast flow deposits, volcanic mudflows, lava flows, and any other deposit from a single eruptive pulse. For detailed information on defining stratigraphic units within volcanic rocks, see Fisher and Schmincke (1984), or Cas and Wright (1987).

6.3 For each layer (pyroclastic, sedimentary, or lava), describe and measure the following characteristics:

Description of Each Rock Unit. Ideally, your descriptions should go onto graph paper taped to a large clip board. This allows you to evaluate relationships at a glance as you are measuring the stratigraphic section. However, because of rain, wind, and carrying around a bulky board, this is not the usual means of recording your observations. You will most likely record your observations and sketches in a notebook, along with thickness and attitudes, to be used later to draw a section in the comfort of your camp or office. Don't worry about using notebook space; it is easier to take copious notes at the time, along with photos and sketches than to wish you had done so later in the office.

- A. What is the relation of the unit to underlying rocks? Determine if there is a sharp erosional or depositional contact, a collection of reworked clastic debris, or paleosoil. Do the deposits drape the underlying topography or are they concentrated in channels and valleys. If they are deposited within a valley, measure the size, orientation and slope of the valley floor.
- B. What is the color or variation in color? Be consistent and use a color chart (Munsell System rock color charts are available from the Geological Society of America).
- C. Within pyroclastic rocks and epiclastic rocks:

1. Grain Size

Field estimates of grain size can be made, using the Fisher (1961) classification, which is parallel with Folk's (1966) classification of clastic sediments. These estimates can be made with a scale and charts for estimating areas. Actual measurements will be made by sample sieving or thin-section studies in the laboratory, but the visual estimates are good enough for measured sections. For coarser materials, including pumice and lithic clasts, they can either be sieved in the field with coarse (>4cm) sieves or measured and described at an outcrop within a designated area outlined on the rock surface (usually around 1m²). These observations are especially important for a study of lithic clasts within a pyroclastic unit. Another technique for observing textural variations within an eruption unit is to measure the length of the 5 largest lithic clasts and the 5 largest pumices.

2. Pyroclast Descriptions

Most of this detailed work will be done within the laboratory, but look for pyroclast and lithic clast characteristics that can be used to uniquely identify this formation or member. These can include color, shape, percentage of phenocrysts, phenocryst types, and variety of lithic clasts. Lithic clasts include those of lag breccias, mesobreccias, and megabreccias (the two latter types are related to catatrophic collapse such as avalanches from sector collapse of a volcano and wall collapse within a caldera).

3. Bedding Sets

A sequence of pyroclastic beds can be used to identify a mappable unit in the field, when used along with other observations. For example, a specific member that you are mapping may consist of a fine-grained ash fallout bed overlain by a surge bed, two pyroclastic flow deposits, and a volcanic mudflow breccia. Thicknesses, and the degree of compaction and welding within the pyroclastic flow deposits may change, but the sequence appears to be unique and helps to correlate units.

4. Grading

Is a bed massive, normally-graded, or reversely graded?

5. Oriented Clasts

Within surge deposits and pyroclastic flows, there may be elongate clasts or accidental debris, such as fossil tree trunks, which can be used to determine flow directions. Measure the orientations of the long axes of as many elongate clasts (or debris) as you can find and average them for each field location.

6. Flow Features

Many surge deposits are characterized by dunes and antidunes. Measurement of implied current directions, description of the type of cross-bedding, and the magnitude of the cross-beds are all useful for evaluating eruption types and processes and for locating vent areas.

7. Degree of Induration or Welding

Is the rock welded, partly welded, or nonwelded? Has the rock been indurated or cemented by post-depositional processes, including vapor-phase alteration within pyroclastic flow deposits, weathering, or hydrothermal acidity? Is there evidence for fossil fumaroles, including pipe-like zones cemented with vapor phase minerals or vertical concentrations of small lithic clasts (segregation pipes)?

8. Sampling

For each distinct unit (not necessarily from all measured stratigraphic sections), collect a sample that is representative of that unit. If the tephra are unconsolidated and coarse-grained, use a field sieve, weigh the size fractions, and collect chunks of the pumice in addition to a split of the less-than-1-mm fraction kept for laboratory sieving. If the rock is consolidated (tuff), break off a sample that you feel is representative of the unit. After describing the variety of lithic clasts, collect samples of each lithic type for thin-section study. Collect samples (if appropriate) for radiometric dating and chemical analysis. Coordinate all sampling efforts with the Sample Coordination Facility.

9. Thermal Remanent Magnetization (TRM)

Most welded tuffs have high magnetic stability and have uniform TRM directions. Polarity determinations of welded ignimbrites can be made in the field, using a portable magnetometer (Lipman, 1975).

D. Lava Flows and Domes

1. Texture

Describe the textural variations within flows or domes, including variations in vesicularity (size, shape, and orientation), phenocryst content and size, brecciation, and flow foliation or layering. Map coarsely pumiceous zones, which can rise diapirically and may be broken or folded by flow movement (Fink and Manley, 1987); variations in relief and vesicularity may show up on aerial photographs of silicic lava flows and can be used to map flow structures.

Flow layering in silicic lavas ranges from sub- μm shears, which have annealed to macroscopic bands of dense glass and slightly vesicular glass. Layering attitudes, measured vertically and over the entire lava flow, can provide information on vent location, and physical properties of the flow.

2. Type of Jointing

Most lavas are broken into blocks by thermal stresses during cooling. The open fractures or joints are often columnar, at right angles to the flow surface and base (normal to the isotherms or cooling surfaces). Fracture surfaces are striated, the striae of which is a record of incremental crack advance during stress buildup in the cooling lava (Ryan and Sammis, 1978).

Columnar joints can range in size from a few tens of centimeters to over a meter wide and up to 30 m long (in some thick plateau basalt flows). The columns can have as few as three or as many as seven sides; most appear to have five or six sides (Williams and McBirney, 1979). Mapping column orientations can sometimes help determine lava flows boundaries (especially useful where outcrops are poor); for example, within a valley-filling lava flow, columns in the center of the valley would be vertical but oriented at an angle along the valley walls, and perpendicular to those walls which had acted as heat sinks during cooling of the lava flow. Similar columnar jointing can also be found in dikes, plugs, and lava lakes.

Mapping the size, width, and extent of cooling joints in lava flows exposed at the surface may be of considerable use in estimating their permeability.

3. Petrology

Field identification of lava type. Use whatever petrographic classification with which you are familiar, but be consistent. Remember that the descriptions should be the best possible, but that you will probably change these descriptions once you have thin sections for petrographic analysis and chemical analyses, especially in finely-crystalline rocks.

4. Type of Lava Flow

If possible, describe the type of lava flow. Most basaltic lavas can be described with the terms "pahoehoe", "aa", and "block lava". Include a description of basal breccia and lava tubes or channels if they are visible.

5. Thermal Effects

Thermal metamorphism of rocks underlying the lava flows, which includes the oxidation of soil layers or older rocks, formation of pipe vesicles during heating of water in soil or bogs, or desiccation of clastic sedimentary rocks.

E. Thickness

Measure thickness of all mappable subdivisions (eruption unit, member, or formation) and all of its members or textural subunits. Measure distances from the base of a unit to significant textural features and boundaries.

F. Correlation of Volcanic Rock Units

The means of correctly identifying a particular eruption unit is not difficult if it is small and covers a small area, for example a small-volume rhyolite flow where it is possible to walk from one end to the other. However, even in these cases, describing the lithologic characteristics necessary for correlation may be necessary; for example, if the underlying vent or dike is drilled and a correlation is needed between dike rocks and the flow.

The ability to identify and correlate eruption units becomes much more important if the units are large, extensive, and within a tectonically complex area. If a pyroclastic unit (either fallout deposit or ignimbrite) is to be traced, either for the purpose of determining its volume or its utility as a stratigraphic marker across complex terrain, then correlation criteria must be established. Field work within calderas requires that pyroclastic deposits exposed around the margins be correlated with thick caldera-fill deposits; these tuffs are from the same eruption; but may have drastically different textures.

A whole branch of volcanology, *tephrochronology*, has been developed around the need for correlating volcanic ash deposits (e.g., Wilcox, 1965; Self and Sparks, 1981). Correlation of ash beds requires a unique combination of mineral phases, glass compositions, and particle shapes (e.g. shard types and pumice characteristics) for each deposit. If you are lucky enough to be working with a petrographically unique ash, then it is possible to identify it with a hand lens plus a reference sample of the known deposit. If there are several ash beds of similar composition or appearance, it may be necessary to use chemical analyses of the glass pyroclasts, including trace elements for correlation. Radiometric age dates are useful, but expensive. Bulk chemical analyses are known to be poor for correlation, because gravitational segregation of mineral phases from a glass-shard-laden eruption plume increases with distance from the source. Refractive indices (r.i.'s) of glass shards, at one time used for correlation, are difficult to utilize because of changes in the r.i.'s with alteration and hydration of the glasses from one depositional environment to another.

Correlation of ignimbrites can be difficult because of facies variations, the degree of welding, post-depositional alteration, and chemical zonation of large-volume eruption units. For example, it is difficult to quickly correlate a nonwelded ignimbrite on the outer slopes of a volcano with densely-welded, hydrothermally-altered ignimbrite from the same eruption within the thick caldera fill. Hildreth and Mahood (1986) have reviewed techniques of correlating ignimbrites and conclude that the following observations are the most reliable:

1. Careful geologic mapping of the whole unit.
2. Indicating stratigraphic position.
3. Noting thermal remnant magnetic directions within welded tuffs and high precision K-Ar ages.
4. Noting a distinctive suite or lithic clasts.
5. Noting petrographic characteristics within pumice clasts, pyroclast shapes, and unusual phenocrysts.

7.0 REFERENCES

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8.0 RECORDS

Field observations will be kept in the following manner:

- (1) Field notebooks.
- (2) Where appropriate, large sketches will be made of outcrops with pencil and later inked in the office. This approach is particularly appropriate in most cases where a stratigraphic section is being measured.

- (3) On large outcrops or along entire sections of a canyon wall the base for recording these details will be enlargements of photographs taken from the opposite canyon wall with a large-format (8" X 10" negative) camera.
- (4) Photographs of field details may be taken with 35 mm or Polaroid camera. The camera should have a built-in date and time that appears on the negative, which will be recorded in the field notebook. Prints prepared for analysis or use in the field (for annotation with ink) will be at the discretion of the investigator. Proof sheets will be filed along with the negatives.

9.0 ATTACHMENTS

N/A